WP5 Floating Futures

Prof Feargal Brennan
Supergen ORE Hub – Co-Director
University of Strathclyde

Dr Anastasia Ioannou
Supergen ORE Hub – Research Associate
University of Strathclyde

Dr Yibo Liang
Supergen ORE Hub – Research Associate
University of Strathclyde
Work Package Outline

- **Aim:** Assess the potential of very large ORE structures, including floating, and address key technical challenges to the design, deployment and operation of such structures.

- **Objectives:**
  - Limitations in scale and depth for floating offshore renewable energy platforms
    - Investigation of current floating support structures
    - Minimum water depth for feasibility of floating structures and to assess the limiting parameters
  - Development of hydroelastic models for VLFS
    - 2D Hydroelastic analysis - Currently Stage (Hinge, wave, loads effect)
    - 3D Hydroelastic analysis methodology development
  - Structural models of VLFS & experimental work
    - ULS Structural Analysis
    - FLS Structural Analysis
    - Experimental V&V
    - Expandable and reconfigurable floating arrays systems
    - Proof of concept for modelling frameworks and trade off methodology and Assessment of optimal floating multi platform systems
  - Techno-economic and environmental assessment of VLFS
    - Investigation of the structure’s material efficiency, estimation of unit cost of tonnage per produced MWh
    - Development of maintenance strategies of the structures (reducing O&M and manned operations)
    - Assessment of VLFS array limits in structure, control, operation and ecological reasoning
Current floating support structures

• To date, common platform concepts for floating wind turbines can be classified into four main groups:

1. Spar
2. Semi-submersible (semi-sub)
3. Tension-leg platform (TLP)
4. Barge

Sketch of the current deep water offshore wind platforms (Ideol, 2019)

Share of different floating foundation types for grid-connected wind turbines at the end of 2018 (WindEurope, 2019)
## Current floating support structures

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Spar-buoy</th>
<th>Semi-sub</th>
<th>Tension leg platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple design</td>
<td>Ability to operate in shallow waters</td>
<td>Low structural mass</td>
<td></td>
</tr>
<tr>
<td>Few moving parts</td>
<td>Low vessel requirement – only basic tug boats</td>
<td>Onshore turbine assembly</td>
<td></td>
</tr>
<tr>
<td>Excellent stability</td>
<td>Onshore turbine assembly</td>
<td>Excellent stability</td>
<td></td>
</tr>
</tbody>
</table>

## Weaknesses

<table>
<thead>
<tr>
<th>Spar-buoy</th>
<th>Semi-sub</th>
<th>Tension leg platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep waters</td>
<td>High structural mass to provide sufficient buoyancy and stability</td>
<td>High loads on mooring and anchoring system</td>
</tr>
<tr>
<td>OWT assembly requires dynamic positioning vessels and heavy-lift cranes</td>
<td>Complex steel structures with many welded joints</td>
<td>Challenging installation process</td>
</tr>
<tr>
<td>Large draft limits ability to tow the structure back to port for repairs</td>
<td>Potentially costly active ballast systems</td>
<td>Bespoke installation barge required</td>
</tr>
</tbody>
</table>

Stability triangle with annotation of common offshore wind concepts

- Ballast stabilized
- Spar
- Barge
- Semi-Sub
- TLP
- Buoyancy stabilized
- Mooring stabilized

---

**offshore renewable energy**
Current floating support structures

• “One turbine one platform”

WindFloat during tow (WindFloat, 2014)
Current floating support structures

- Parametric analysis of floating support structures

Buoyancy

\[ M_{Total} = \rho_w V \]

\[ (\rho g l_y + F_b z_{CB} - F_w z_{CG}) \sin(\theta) \]

\[ = F_t (h_{hub} + f_b + z_{CB}) \]

Restoring

Spar type: Parametric analysis considering the steel (a) and the concrete (b) as structural material.

Semi sub type: Parametric analysis considering the steel (a) and the concrete (b) as structural material.

Barge type: Parametric analysis considering the steel (a) and the concrete (b) as structural material.
Current floating support structures

- Parametric analysis of floating support structures

<table>
<thead>
<tr>
<th>Typology</th>
<th>Structural Material</th>
<th>Ballast Material</th>
<th>$f_b(m)$</th>
<th>$d(m)$</th>
<th>$h_p(m)$</th>
<th>R(m)</th>
<th>$d_c(m)$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barge</strong></td>
<td>Steel</td>
<td>Seawater</td>
<td>5</td>
<td>46.7</td>
<td>5</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Seawater</td>
<td>5</td>
<td>17.3</td>
<td>5</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Seawater</td>
<td>5</td>
<td>54.7</td>
<td>5</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Concrete</td>
<td>5</td>
<td>17.3</td>
<td>5</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td><strong>Spar</strong></td>
<td>Steel</td>
<td>Seawater</td>
<td>10</td>
<td>158</td>
<td>135.2</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Seawater</td>
<td>10</td>
<td>75.25</td>
<td>26.2</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Seawater</td>
<td>10</td>
<td>200.8</td>
<td>185.7</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Concrete</td>
<td>10</td>
<td>74.2</td>
<td>27.8</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td><strong>Semisubmersible</strong></td>
<td>Steel</td>
<td>Seawater</td>
<td>10</td>
<td>20</td>
<td>16</td>
<td>13.2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Seawater</td>
<td>10</td>
<td>20</td>
<td>16</td>
<td>9.9</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Concrete</td>
<td>10</td>
<td>20</td>
<td>16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Prices of steel and concrete

<table>
<thead>
<tr>
<th>Material</th>
<th>Price</th>
<th>Measurement unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>537</td>
<td>£/tonne</td>
</tr>
<tr>
<td>Concrete</td>
<td>77</td>
<td>£/tonne</td>
</tr>
</tbody>
</table>

Manufacturing complexity factors

<table>
<thead>
<tr>
<th>Material</th>
<th>Manuf. complexity factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>110%</td>
</tr>
<tr>
<td>Concrete</td>
<td>200%</td>
</tr>
<tr>
<td>Barge</td>
<td>170%</td>
</tr>
</tbody>
</table>

Material and fabrication cost of support structure and ballast

Structural Support mass

Supergen Offshore Renewable Energy
SUPERGEN Wind Hub Integrated cost model

- Cost/revenue framework for floating wind turbines

- Online tool: https://supergenwind.shinyapps.io/rshinyappfolder/
Current floating support structures

- The **draft effect** on the design of FOWT is well studied.
- The **Waterplane area** is still limited at a relatively small range.
Future floating support structures

• Could two or more turbines seat on one platform?

P37 multi turbines platform (Floating Power Plant AS, 2013)

Artist’s impression of the hybrid 50MW platform (Energy Island Ltd, 2009)
Future floating support structures

• Comparison of the key features between current offshore floating wind platforms and VLFS platforms

• VLFS allow the consideration of relatively shallow water draft floating platforms

<table>
<thead>
<tr>
<th>Current offshore floating wind platforms (Spar, Semi-sub, TLP and Barge)</th>
<th>VLFS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong></td>
<td>Low</td>
</tr>
<tr>
<td><strong>Waterplane area</strong></td>
<td>Small</td>
</tr>
<tr>
<td><strong>Hydroelastic issue</strong></td>
<td>No</td>
</tr>
<tr>
<td><strong>Material requirement</strong></td>
<td>Low</td>
</tr>
<tr>
<td><strong>Main deck area</strong></td>
<td>Small</td>
</tr>
<tr>
<td><strong>Design life</strong></td>
<td>Short</td>
</tr>
<tr>
<td><strong>Number of turbines</strong></td>
<td>Small</td>
</tr>
<tr>
<td><strong>Manufacture</strong></td>
<td>Hard</td>
</tr>
<tr>
<td><strong>Installation of wind turbines</strong></td>
<td>Hard</td>
</tr>
<tr>
<td><strong>Operation cost</strong></td>
<td>High</td>
</tr>
<tr>
<td><strong>Maintenance cost</strong></td>
<td>High</td>
</tr>
<tr>
<td><strong>Power generating capacity for wind turbine</strong></td>
<td>Low</td>
</tr>
</tbody>
</table>
Future floating support structures

- Trade off between bending moment and displacement

Bending moment  
Motion amplitude
Future floating support structures

- Impact of installing the wind turbine

VLFS mass vs Wind turbine system mass
Future floating support structures

• Preliminary observations

VLFS allow the consideration of relatively shallow water draft floating platform.

Traditionally long barge type floaters attract high bending moments.

Hinges can alleviate bending stresses.

However, hinges also introduce huge displacements.
Future work

• A fundamental new hydroelastic method is under development.

• Investigation of the structure’s material efficiency, estimation of unit cost of tonnage per produced MWh.

• Techno-economic assessment of the VLFS configuration. Is it beneficial to have flat platforms with multiple installed wind turbines?

• Techno-economic aspects of maintenance strategies.

• Potential for non-grid connected applications.
Potential interactions with other WPs

- Work package 1. Environmental Impact of ORES.
- Work package 1. Socio-economic impact of ORES.
- Work package 1. Maintenance strategies of the VLFS (partitioning the VLFS and tug to the shore for maintenance) and of wind turbines (OPEX vs CAPEX).
- Work package 2. Trying to define the extreme environment sea condition in order to predict the performance of the structure accurately.
- Work package 3. Defining the optimum spacing ratio for offshore wind turbines. The VLFS can be designed according to the offshore wind turbine array.
- Work package 4. Combining the WEC together with the hinged VLFS.
- Work package 4. Potential experiments which could be performed at Plymouth to validate the hydroelastic code.
- Work package 5. Optimising of the VLFS based on the control system (e.g. Number of hinges for minimum vibration)
Thank you for listening!

Prof Feargal Brennan
Email: feargal.brennan@strath.ac.uk

Dr Anastasia Ioannou
Email: anastasia.ioannou@strath.ac.uk

Dr Yibo Liang
Email: yibo.liang@strath.ac.uk